Introduction

I continue to see questions on the forum regarding electrical problems, ranging from trying to hook up a new accessory to problems with a bike not starting. And to someone unfamiliar with electricity these problems can range from intimidating to downright terrifying. And maybe in some cases, they should be. Doing things wrong can cause a lot of very expensive damage, and can even be dangerous. But that doesn't mean you have to back away from these types of problems. With a little bit of knowledge, there isn't much circuitry on a bike that you can't handle.

This document is intended to assist with understanding motorcycle electrical problems. It provides a brief overview of electricity and electrical circuits and then covers motorcycle circuitry. I know it's probably boring, but if you spend a little time trying to learn these concepts, it will pay big dividends the next time an electrical problem rears its ugly head.

So What Is Electricity Anyway

Electricity is all about a tiny, sub-atomic particle called the electron, which carries a very tiny negative charge. The term electricity refers to the movement of these electrons which are part of an atom, a basic building block of all matter. But let's face it, trying to associate with an electron isn't all that intuitive. So let's use water instead. Water has been used for years to help explain electrical concepts, and the similarities are many.

Some electrical terms that you may have heard are likely: voltage, current, amps, batteries, watts, power, energy, conductors, resistance, impedance, switches, fuses, loads, sources, sinks and inductance. Forget about them for a second. Instead, think about Hoover Dam, Lake Mead and the Colorado River both above and below the dam.

Back in the 1930's I think it was, Hoover Dam was built and backed up the Colorado River to form Lake Mead. Today, huge penstocks guide water from the lake through giant turbines and out to the Colorado River below the dam. Why? Because that water backed up behind the dam creates a lot of pressure. And pressure can be used to perform work.

Now back to electricity. Think of Lake Mead as a battery. Instead of storing water however, it is storing electrical charge. Instead of water molecules . . . electrons. Lots of electrons. And given an outlet, those electrons want to flow somewhere, just like water behind a dam. Now hook a wire to your battery. You just simulated one of the penstocks that guides water out of the lake. Put a door on that penstock, and you have a switch. Next, add a light bulb to your wire. That simulates that giant turbine that is spun around by the water flowing through it. And finally, run your wire back to the battery. That simulates the water flowing back into the river below the dam.

Really, that's all there is too it. Everything else is just detail. Get this part down, and your halfway there.

Don't believe me? Think about it. Your bike has a battery, switches and things that use electricity. All those wires and switches are strictly ways to get the right amount of electricity to the right place at the right time so that electricity can do something useful. And an electrical problem is simply what happens when one of those four things doesn't happen, i.e., the wrong amount of electricity, the wrong place, the wrong time or the thing trying to use the electricity is broken.

Ok, so now let's explain some of those electrical terms that I mentioned earlier. First is a battery. A battery is a source of electricity, or electrical pressure. And electrical pressure is measured in volts. The higher the voltage, the more the pressure. The flow of electricity is known as current, and is measured in amps. The higher the amperage, the higher the flow. The next piece of this is power, volt-amps, or watts . . . ability to do work. Essentially, the capacity of the battery. How much flow can it provide while maintaining pressure. And the last piece is energy, how long can the battery provide a specific flow while maintaining pressure.

Let's look a typical Nomad battery. It is a 12 volt battery, meaning that it can provide 12 volts of pressure. More on this later. It is an 18 amp hour battery. Meaning that in can provide 18 amps of flow at 12 volts for 1 hour, or 1 amp of flow for 18 hours. But is this how it really works? Well, the answer is . . . not exactly.

Here is where some of those pesky details come in.

Here is what a battery has to do. First, it needs to provide a high flow of current while maintaining high pressure in order to start the bike. The starter motor especially does a lot of work to spin the engine. Once, the bike is running, the charging system provides the electricity to keep the bike running. However, the battery still has two jobs to do. One is that it smoothes out the electricity coming from the charging system. And second is that it supplements the charging system with electricity when the bike is idling and the engine isn't spinning fast enough to provide all the electricity the bike needs.

To continue from here, let's assume you go out to the garage and get on the bike to go for a ride. You kick up the side stand, turn on the ignition, and hit the starter button. The starter motor groans, turns the engine over a couple of times and stops. Then nothing. You try again, and this time, the lights on the speedo go dim, and then nothing. What's happening . . . and why? Everything was fine just yesterday.

Well, a number of things could be happening. Let's go back to our water analogy. If the turbine stopped spinning, what could be the problem there? Could be that

Lake Mead is empty. Or maybe the entry to the penstock is clogged. Or maybe the door in the penstock to the tube is stuck closed. Or the switch that controls the door is broken. Or maybe the tube leading water to the turbine has an obstruction. Or the turbine itself is jammed. Or the tube leading from the turbine back to the river is obstructed.

Let’s take them one by one. First . . . Lake Mead is empty. Dead battery. In order for Lake Mead to stay full, it has to have more water going into it than is needed by the turbine. Second, it has to be capable of holding on to that water. Third, it has to maintain the volume of water. Same with the battery. The charging system needs to be able to keep the battery full, the battery must be able to be filled, and the battery must stay filled while it is not being used.

A Nomad battery is considered to be fully charged if the voltage across its terminals is greater than 12.6 volts. At that voltage, it is not quite at capacity, but for all intents and purposes, is capable of doing what it needs to do. So you check the voltage on your battery, and it reads 12.65 volts. Hmm. Seems OK. Fully charged. Well, maybe not. Imagine that Lake Mead all of a sudden, instead of covering hundreds of acres, is just a column of water the same depth, but only the thickness of a straw. There will be exactly the same pressure at the bottom in both cases (not intuitive, but true), but very different capacities to do work. The straw Lake Mead will run out of water almost immediately, and the voltage will drop precipitously. This is what a battery load test checks for. How much current can a battery produce while maintaining pressure, or voltage. Load test fails . . . battery is bad. But in your case, the battery checks out good.

Well, that tells you that it is something wrong in the flow. How do you isolate it? Really critical concept here. Get this one down, and you have most of the other half. Back to the turbine. In order to get full power out of the turbine, there must be a constant, unobstructed flow of water at high pressure to the turbine, and a constant, unobstructed flow of water at low pressure from the turbine. Think small tube going in, big tube going out. Same volume of water in each. So it is the same with every electrical circuit, but with electricity, the turbine is represented by a load. A load is the starter motor, a light, the horn, the ignition coil, anything that needs electricity to work. And for that load to work, it needs a constant, unobstructed flow of electricity at high pressure going in (battery voltage = 12.6 volts to ~14.8 volts), and a constant, unobstructed flow of electricity at low pressure going out (battery ground = 0 volts).

So let’s summarize. A battery is a source of electricity, which flows from the battery to a load. The load uses that electricity to do work, with the used electricity flowing back to the battery. A break anywhere in the circuit . . . a bad battery, bad wiring, bad connection, bad switch, bad fuse, bad load, bad anything . . . and you have an electrical problem.

So how do you find out what's bad? Well, two methods really. One is to just try stuff. A common one is to clean connectors. Over time, connections can oxidize and impede the flow of electricity. Cleaning and re-tightening those connections can sometimes fix the problem. The other method is to take measurements. Here is how that works.

For this, you have to learn the one equation I have in this document. That equation is known as Ohm's Law, and is V=IR, or voltage = current times resistance. You already know what voltage and current are. Resistance is something that impedes the flow of electricity. What this law says is that electrical pressure, or voltage will drop across a resistance proportional to the current flowing through it. This is the key to finding problems by taking measurements. Remember the rules for getting a load to do what it is supposed to do. It must have battery voltage on one side of it, and zero voltage on the other side.

If you add together everything I've covered so far, this is what you come up with. Electricity flows from one terminal of the battery back to the other terminal. During that time travel, the voltage changes from 12 volts at one terminal to 0 volts at the other terminal. The volume of that flow (current) is based on the total resistance in the circuit along that flow according to the formula V=IR. An example:

Voltage = 12 volts

Headlight has a resistance of 4 ohms.
Current flow = 12/4 = 3 amps.
Watts = 12 x 3 = 36 watts.

Where things go wrong is when a resistance appears in the circuit that shouldn't be there. Let's just say that some corrosion builds up in the connection from the battery to the battery cable. And that corrosion creates a resistance of ¼ ohms. In this case, we have the following:

Voltage = 12 volts

Headlight has a resistance of 4 ohms.
Corrosion creates a resistance of ¼ ohms.
Total resistance = 4.25 ohms.
Current flow = 12/4.25 = 2.8 amps.
Voltage drop across corroded switch = 2.8 amps x 0.25 ohms = 0.7 volts.
Voltage drop across headlight = 2.8 amps x 4 ohm = 11.2 volts.
Watts consumed by headlight = 2.8 amps x 11.2 volts = 31 watts
Watts consumed by corrosion (as heat) = 2.8 amps x 0.7 volts = 2 watts.

So from this you can see that a little corrosion cuts the voltage seen by the light by 0.8 volts, and reduces its output by over 13%.

Let's do the same exercise with the starter motor, and assume it draws 48 amps.

Voltage = 12 volts
Starter motor draws 48 amps.
Starter motor has a resistance of 12 / 48 = ¼ ohm.
Watts = 12 x 48 = 576 watts

And with a little bit of corrosion:
Voltage = 12 volts
Starter Motor has a resistance of ¼ ohm.
Corrosion creates a resistance of ¼ ohm.
Total resistance = ½ ohm.
Current flow = 12/0.5 = 24 amps.
Voltage drop across corroded switch = 24 amps x 0.25 ohms = 6 volts.
Voltage drop across starter motor = 24 amps x 0.25 ohms = 6 volts.
Watts consumed by starter motor = 24 amps x 6 volts = 144 watts.
Watts consumed by corrosion (as heat) = 24 amps x 6 volts = 144 watts.

In other words:
The starter motor will not have enough electricity to turn over. It will stall, draw even higher current, and probably burn out.
The connection at the battery will get very hot, and burn the wires.
The solenoid may well overheat and burn out.
There will be insufficient voltage to trigger the ECU, which needs to see something north of 11.5 volts.

The key concepts here are:
Any unwanted resistance in a circuit will reduce the ability of a load to do what it is supposed to do, and the higher the current flow / bigger the unwanted resistance, the more effect it will have.

Any unwanted resistance will give itself away by showing a voltage drop across it that is proportional to the current flowing through it.

So with all this figured out now, let's go back to troubleshooting our battery problem, with the first step being to understand how a good battery should act.

A good battery:
Is considered to be fully charged if it has a resting voltage of 12.6 volts or higher. Maximum will be about 12.9 (not including any temporary surface charge).

A fully charged battery will discharge its capacity at the rate of about 1% per day, meaning it will lose about 30% of its capacity over the course of a month. Or a 20 amp-hour battery will be down to about 14 amp-hours after a month. (Don't confuse capacity with voltage here. A battery at 75%

of capacity will read about 12.5 volts. At 50%, about 12.25 volts, and at 25%, about 12 volts.)

A battery is considered to be discharged if it has a resting voltage that is under 12 volts, and defective if charging does not bring it up to 12.6 volts with the battery being able to hold that charge.

A battery requires a voltage of approximately 13.6 volts – 15.5 volts to re-charge. Less than that is insufficient to charge the battery. More than that and the battery will overheat and eventually be destroyed.

After a battery is charged, a surface charge will remain on it for several hours and show a voltage of over 13 volts. This charge will dissipate to something around 12.8 or 12.9 volts.

A battery can show a voltage of 12.6 volts and still be bad if it cannot perform to capacity, meaning it cannot deliver suitable current while maintaining voltage. A load test will check for this. A typical load test is roughly equivalent to hooking up 18 headlights to the battery for 15 seconds and making sure that the voltage returns above 12.6 volts after the headlights are disconnected.

So in our case of the bike not starting, we clean off the connector where the negative battery cable connects to the engine, removing a little bit of corrosion that has built up there, and we are back in business.

Any other electrical problem on the bike can be isolated following a similar path.

- Study a wiring diagram to figure out the circuit from battery post to battery post that includes what is not working right.
- Determine what components are in that circuit . . . switches, fuses, etc.
- With your multimeter,
    - Measure either the resistance across things with the power off
    - Or the voltage across things with the power on
- Switches, fuses, etc. should show zero resistance and zero voltage drop
- Loads should show a resistance and full battery voltage across them

OK, with that behind us, let’s go right back to the beginning and talk a little bit about the theory, remembering that electricity is really about the flow of a sub-atomic particle called the electron, which carries a very small negative charge or voltage on it. In the process, we’ll recap some of the key things we’ve stated earlier.

First, the electron and its relationship to voltage. If more electrons exist at one spot than at another spot, then there is a difference in charge between those two spots. This difference is known as voltage, potential difference, or electromotive force, and is measured in volts. An excess of electrons forces electrons to flow through a conductor.

A conductor (such as a wire, terminals, junctions, etc.) is a material through which electrons can flow. In a good conductor, such as copper, tin, steel, silver, gold and others, electrons flow easily. In a poorer conductor, such as carbon or lead or corroded or oxidized or rusted copper or steel, electrons flow less easily. A non-conductor is one which won't allow electrons to flow, and is known as an insulator. An example of an insulator is the covering on a bike's wires which protect the conductor and ensure that the electrons flow to the desired destination or load, and return to the source. Generally speaking, when referring to conductors, we're referring to wires connecting sources (such as your battery or the stator) to controls (such as switches, coils, computer modules, etc.) and then to loads (such as lights, rectifiers, regulators, turn signal flashers etc.).

A flow of electrons is called current, and is measured in amperes. All conductors and loads offer a restriction to the maximum flow of electrons out of and back to the terminals of a source and indeed within the source itself. We call this restriction, resistance, and measure it in units known as Ohms. In practice, all wiring, and any other item through which a current of electrons flows, has some resistance and as such this must be accounted for when determining how much current can maximally flow.

For a flow of electrons to be useful, it must be guided. Lightning is a good example of an unguided flow of electrons. A circuit is used to guide the flow of electricity. When a source of electricity is connected to something so that work can be performed, it is known as a circuit. The thing performing the work, like a light bulb, is known as a load. A typical circuit consists of the source of electricity, the load, and the connections between the source and the load.

NOTE: Automotive, motorcycle and many chassis type of circuits are known as "ground-return" circuits, whereby the frame constitutes at least one of the conductors. This is done to simplify wiring and thus should always be considered as part of the circuit.

There are a couple of basic relationships between voltage and current that need to be understood. In a given circuit, the higher the voltage (potential difference between the two terminals) of a source, the more current will flow. The better the conductors, the more current will flow.

If a circuit is not complete, either intentionally through an open switch or via a broken connection, then no current will flow.

If a circuit is shorted, then the maximum current producible by the source will flow, limited only by the resistance of the conductors until the fuse blows (think heat and even fire).

Electricity comes in two flavors. DC and AC. DC means Direct Current. It means that there is a voltage between two points, and that voltage is constant. It also means that current also flows in only one direction. A battery provides DC electricity. It is a constant 12 volts. AC means Alternating Current. It means that there is a voltage between two points, and that voltage changes over time, like a wave. It also means that the current changes direction, first going in one direction and then going in the other direction. Household electricity is AC electricity. It waves 60 times a second. An alternator in a vehicle charging system is also AC electricity. It waves proportional to engine speed.

Loads come in three flavors. These are resistive (think of water flowing through pipes of different diameter or pipes with obstructions in them to restrict the flow of water), capacitive (think of a pressure tank) and inductive (think of two impellers, immersed in a fluid, like a torque converter, where the turning motion of one impeller is communicated to the other impeller through the motion of a fluid.)

A resistive load is a load that restricts the electron flow. A light bulb is a resistive load. The relationship between voltage and current in a resistive load is known as Ohm's Law. It is $v = iR$, or voltage = current times resistance. Resistive loads typically do work by creating heat or light. The equation describing this is $w = vi = i^2R = v^2/R$, or watts = voltage times current = current squared times resistance = voltage squared divided by resistance. Energy = work times time, as an example, a watt minute or a kilowatt hour. A 100 watt light bulb which is turned on for 10 hours uses 1 kilowatt hour of energy.

A capacitive load is a load that stores an electric charge. The condenser in a points ignition is a capacitive load. The relationship between voltage and current in a capacitive load is $i = Cdv/dt$, or current = capacitance times the rate of change of voltage with respect to time. A capacitive load looks like an open circuit to DC electricity, but a resistance to AC electricity. The higher the frequency of the AC electricity (the faster it waves), the lower the resistance. (The correct term for resistance in AC circuits is impedence.)

An inductive load is a load that interacts with a magnetic field. Both a stator in an alternator and an ignition coil are inductive loads. The relationship between voltage and current in an inductive load is $v = Ldi/dt$, or voltage = inductance times the rate of change of current with respect to time. An inductive load looks like a short circuit to DC electricity, but a resistance to AC electricity. The higher the frequency of the AC electricity (the faster it waves), the higher the resistance (impedence). AC electricity in an inductor produces a changing magnetic field. This changing magnetic field will induce AC electricity in another inductor that is in the field. This is how a coil works.

Wires, connectors, fuses and switches are also electrical components. Their purpose is to carry electricity from a source to a load to a sink, and to turn the flow of electricity on and off. They themselves should never act like a load. If they do, they can generate heat, light and sound, usually with some sort of negative implication. At a minimum, they will rob power from the intended load.

Typical resistive loads are lights. Capacitive loads are not common on a bike. The ignition condensors on a points ignition are the only obvious ones that come to mind. Inductive loads include the ignition coils, the starter motor, the starter relay, electronic ignition, and the alternator.

Electric motors are devices that use inductive loads, AC electricity and magnets to produce physical motion. An alternator / generator is an electric motor operated in reverse. It uses physical motion, inductive loads, and magnets to produce AC electricity. A generator produces its output from the rotor (the part that moves). An alternator produces its output from the stator (the part that doesn't move). Alternators are more reliable because if permanent magnets are used in the rotor, there are no brushes to wear out.

Motorcycle Circuitry

Motorcycle circuitry can be divided into two main pieces. One piece is the load circuit. The other piece is the charging circuit.

In the load circuit, electricity is supplied by the wiring harness to all the various loads on the bike. These include lights, horn, instruments and ignition coil. Electrical energy is converted into light, heat, sound and motion. The electricity used is DC electricity.

In the charging circuit, electricity is generated by converting mechanical energy, the rotation of the engine, into electrical energy. The electricity produced is AC electricity, and is produced by the alternator. The rectifier converts the AC electricity produced by the alternator into DC electricity (actually more like AC with the negative side chopped off). The regulator insures that the DC electricity coming out of the rectifier never exceeds a voltage that would damage the bike.

The battery supplies DC electricity to the load circuit when the bike is not running. The charging circuit provides DC electricity when the bike is running. (The battery acts like a filter in this case, smoothing the fluctuations in the alternator output.)

When everything is running correctly, motorcycle circuitry works as follows:

- When the bike is totally off, electricity from the battery cannot flow to the bike because it is stopped by the ignition switch.

- When the ignition switch is turned on, electricity can flow to the kill switch and to all the other loads on the bike, depending on whether their individual switches are turned on and off.
- When the kill switch is turned on, electricity can flow to the ignition coils and the starter button.
- When the starter button is pressed, electricity can flow to the starter relay.
- When the starter relay is activated, electricity can flow from the battery to the starter motor, which cranks the engine.
- When the engine is running:
    - The points or electronic ignition switch the current to the coil primaries on and off, which produces spark at the spark plugs.
    - The charging system generates electricity to replace electricity taken from the battery and to power all the various loads on the bike.

Motorcycle Electrical Components

Battery

The battery forms the basic source of electricity on a bike. We can use this source whether the bike engine is shut off or running. Because the battery can be depleted (it is rechargeable), we provide another source, run by the engine, which is made up of an electricity-generating system comprised of the stator, the rotor, the rectifier and the regulator.

Switches

Ignition Switch: Controls whether electricity can flow to any of the loads on the bike. When it is off, the battery output is totally disconnected from all the loads on the bike. When it is on, the battery output can flow to various loads on the bike, depending on whether individual switches are turned on or off.

Kill Switch: Usually controls whether electricity can flow to the ignition coils and to the Starter Relay. When it is off, pressing the Starter Button doesn't do anything.

Starter Button: Controls the flow of electricity to the starter relay. When it is pressed, the starter relay is activated, connecting battery positive to the starter motor.

Horn Button: When pressed, connects battery negative to the horn. (Note that unlike most circuits, the horn button does not connect battery positive to the horn. Instead, battery positive is always connected, and the horn button connects battery negative (ground) to the horn.

Light Switch: When switched on, connects battery positive to the Low-Beam headlight and the tail light.

Hi-Beam Switch: When switched, disconnects battery positive from the Low-Beam headlight and connects battery positive to the High-Beam headlight.

Front Brake Light Switch: When the front brake lever is squeezed, connects battery positive to the brake light.

Rear Brake Light Switch: When the rear brake pedal is pressed, connects battery positive to the brake light.

Turn Signal Switch: When switched, connects battery positive to the appropriate turn signals. Current flows through the turn signal relay, causing the turn signals to blink.

Relays (Note: As stated earlier, high current flow can cause a lot of wear on a switch, just like high water flow can cause a lot of wear on a washer in a spigot. This wear can be reduced however by using heavier duty components in the switch. That increases the size however, making it difficult to mount a high-current switch on say, the handlebars. So relays are used, a relay is strictly a heavy duty switch that is controlled by a light duty switch.)

Starter Relay: When activated by the starter button, connects battery positive to the starter motor.

Turn Signal Relay: When current flows through the turn signal relay, it heats up and switches off. It then cools off and switches back on. It will repeat this cycle over and over, causing the turn signals to blink. If there is insufficient current flow through the relay, the turn signals will not blink, often the first sign of a dying battery, or failing charging system.

Ignition

Coils: Converts low voltage from the battery (12 volts) to high voltage (20,000 – 30,000 volts). This voltage is high enough to jump across the spark plug gap.

Points Ignition: Mechanically switches current flow through the coil primary winding on and off. Each time the current flow is turned off, the electric field around the primary coil winding collapses, inducing the high voltage in the coil secondary winding.

Electronic Ignition: Does the same thing as the points, but using electronic components.

Condensors (point ignition): When the points open, a voltage spike is induced in the primary circuit. This spike can jump across the points gap and cause them to pit. The condenser absorbs this spike and charges up (think static electricity on a doorknob in winter). When the points close, the condenser discharges to ground through the points. (think touching the doorknob).

Charging

Alternator

Rotor: Creates a fluctuating magnetic field. It is connected to the engine and turns as the engine turns.

Stator: It sits in the fluctuating magnetic field produced by the rotor. An AC current is induced in the stator windings by the fluctuating magnetic field produced by the rotor.

Rectifier: Uses diodes to chop off the negative part of the AC current produced by the stator. A diode conducts electricity in one direction, but not in the other. Think of a pipe with a one-way valve in it sitting in ocean waves. When a wave hits one end of the pipe, water flows through the valve. When the wave passes, water cannot flow back into the ocean. The effect is pulses of water. Same with a rectifier.

- Diodes: A typical motorcycle rectifier uses six silicon diodes, two for each stator output. One diode is between the stator output and ground. The other diode is between the stator output and the rectifier output.

Regulator: Conducts electricity only if the voltage across it exceeds a certain value. In a bike charging system, this value is a couple of volts above battery voltage, or about 14.5 volts. Think of a bucket of water with an overflow pipe. (A very simple regulator would consist of a single zener diode which would conduct at approximately 14 volts. A more complicated design might consist of a silicon-controlled rectifier with its gate controlled by a separate sense wire and additional circuitry. In the first case, if the rectifier output exceeded 14 volts, any attempt to increase the voltage further would shunt additional current through the zener diode to ground. In the second case, the sense wire can be connected directly to the point that needs to be regulated, thereby providing the opportunity for better voltage regulation (or worse, if the wire is hooked up to the wrong place). In more sophisticated designs, the output voltage can be adjusted.

Battery: Provides a rechargeable source of DC electricity to the bike.

Wiring Harness: Carries electricity (current flow) from the battery to all the various loads on the bike. In general, return current flow is through the engine casing and the bike frame.

Other Components

Fuses / Fusible Links: Electrical components that are designed to open up if the current through them exceeds a specified value. This protects downstream circuitry from being fried.

Lights: Resistive loads that glow from heat produced by the current flowing through them times their resistance.

Horn: Inductive load that vibrates a magnet connected to a diaphragm, producing audible sound. There are other types, such as air horns.

Instruments: Combination of resistive loads (lights), and inductive loads (pickups, meters).

Troubleshooting Methodology

Sometimes a load does not do “useful” work, or it does it at the wrong time or for the wrong reason. It is for this reason that we need to understand electricity and how to troubleshoot it.

When something goes wrong with the electrical system on a bike, there can be many symptoms. The bike may not start or it may run poorly. Lights may be dim. It may run for a while and then die. It may run but once shut off, not start again. The starter might spontaneously start while you are riding. There may be multiple symptoms. A particular part may not work, such as the horn or the lights, or the turn signals. There may be no spark or weak spark. And it is not uncommon for an electrical problem to cascade, and cause other electrical problems, all of which must be fixed before things will be right again. It is not always easy to determine if any given problem is caused by something wrong with the electrical system. Some of the most baffling problems can be caused by open ground connections, where current flow can take some pretty interesting and unexpected paths with sometimes some pretty bizarre results. But bottom line is that in order for any engine to run, it needs fuel, compression and spark. If the spark is compromised, so is the running of the bike.

The two basic steps for solving any electrical problem are the following:

- Determine that you in fact have an electrical problem.
- Isolate the defective part.

To isolate a (load) part that doesn't work, we have to:

- See that a source of electricity exists - we measure its voltage or otherwise determine its ability to run the load in question.
- That the voltage we measured can be seen across the load (device . . . headlight, ignition module, coils etc., and that . . .
- It can be, or is controlled according to when we want it to be . . . headlight switch turned on . . . points or ignition module energizing the coils, etc.

The tools at your disposal are the following:

- A wiring diagram for your bike, which shows you what is connected to what.
- A good multimeter, which allows you to measure voltage and resistance.
- At least a basic understanding of electricity and the relationships between voltage, current and resistance.
- A knowledge of what values of voltage and resistance are normal, and what values indicate a problem.

The methodology is as follows:

- Use the wiring diagram to determine the circuit that is not acting properly, determine the components of that circuit, and determine the expected electrical values for that circuit.
- Using your multimeter, measure the actual values along the circuit, looking for discrepancies from the expected. Can be both voltage and resistance. Usually, you will not measure current, although some meters allow for this.
- Slowly remove other things connected to the circuit until the discrepancy goes away. (Alternatively, one can disconnect everything and slowly add things until the discrepancy appears.)
- Test the part that caused the discrepancy, and repair / replace if verified as bad.

What do you use Ohm's Law For:

Everything in an electrical circuit has some resistance, even wire. (There is no such thing as zero resistance, although at absolute zero, -459.69 degrees F, resistance approaches zero (super-conductivity). Personally, I prefer not to ride when it gets that cold, so it doesn't affect me much.) However, resistance in wire is very small and should measure out at zero for all intents and purposes. Ohm's Law tells you voltage = current times resistance, or that current flow = voltage divided by resistance. You also know that power = current squared times resistance. And that power generates heat and consumes energy. So in order for a load to get the maximum power (a headlight to be as bright as possible), the resistance of everything else in the circuit (wiring, switches, connections, etc) must be as low as possible, because any resistance in these components will rob the headlight of power.

So Ohm's Law can tell you if something isn't connected well. If there is a voltage difference between two points that should be connected directly together, such as two ends of a wire, and current is flowing through that connection, it means that there is resistance in that wire. There shouldn't be. If there is a resistance between two points that are connected directly together, such as two ends of a wire, it means that there will be a voltage drop in that wire when current flows through it. There shouldn't be. Only loads should show measurable resistance. Only loads should have different voltages on each side of them, usually battery voltage on one side and zero voltage (ground) on the other. This is an important concept.

Consider a simple circuit with one continuous path from one terminal of a source to the other. This is known as a series circuit. If more than one series circuit shares a common source, we refer to the combination of those as a parallel circuit. These two terms represent the most basic circuit forms found in actual use. One example on a bike of a series circuit by itself would be the horn circuit. An example of parallel circuit would be the instrument lights for one and perhaps the headlight and taillights combined to form another.

In a series circuit, current flow is the same in all parts of the circuit, just as the water flow in a single hose is the same in all parts of the hose. If a simple light circuit allows 3 amperes of current to flow, then its 3 amperes can be measured in the wires and through the frame back to the battery. In a series circuit, the sum of all the voltage drops equals the voltage of the source. Thus if we measure 12.0 across the battery, we might see that there's a 0.2 volt drop to the fuse (a protection device that burns open if too much current flows), perhaps 0.2 volt drop across the switch operating the light.....11.5 volts across the light and 0.1 volt from the light to the battery negative terminal. There's only 1 path . . . it all has to add up. And with 3 amps and 12 volts, the total resistance of the circuit is 4 ohms. 3 times 4 = 12.

Source = 12 volts

Fuse = 0.2 volts / 3 amps = 0.067 ohms
Switch = 0.2 volts / 3 amps = 0.067 ohms
Path from light to battery = 0.1 volts / 3 amps = 0.033 ohms
Light = 11.5 volts / 3 amps = 3.833 ohms

Note that if this represented an actual situation, consider the voltage drop across the switch. At 0.2 volts, the work performed by the switch would be 3 squared times 0.067 or a little over ½ watt. That work would be generated as heat. It may not seem like much, but over time, that heat could cause problems, even a fire, not to mention robbing the light of a ½ volt total and cutting its brightness noticeably.

Likewise, in a parallel circuit, the sum of the current flows from and to each individual load will equal the total current flow from and to the source. The voltage drops across each load will be equal because they all see the same source. And the current flow through each path of the circuit can be calculated in a manner similar to the above.

These concepts are summarized below and are critical for troubleshooting an electrical problem.

KEY POINTS:

- In a series circuit, the current is the same in all parts of the circuit and the voltage drops across each component of the circuit must add up to the voltage of the source.
- In a parallel circuit, the voltage is the same across all parts of the circuit and the current flow through each path of the circuit must add up to the total current out of and back to the source.
- In order for a voltage difference to occur between two points that are connected to each other, current must be flowing through the connection and there must be a resistance (load) in the connection. A voltage difference at two ends of a wire or on two sides of a closed switch is bad. It means they are either not connected, or not connected well.
- In order for current to flow through a load, there must be a voltage difference between one side of the load and the other, and there must be a complete path from battery negative to the load and back to battery positive again.
- In general, the full battery voltage should be dropped across any load on a bike. One side should be at battery voltage. The other side should be at ground (0 volts). If there is a difference between battery voltage at battery positive and battery voltage at the load, there is a connection problem in the wiring from the battery to the load. If the ground side of a load is anything but zero, there is a connection problem in the wiring from the load back to battery negative.

- Testing always involves two tests. A No-Load Test and a Load Test. A No-Load Test checks to make sure two points are connected to each other. There is a connection to the load from the battery, but no connection back. Since there should be no current draw, there should be no voltage drop, and the two points should be at the same voltage. A Load Test checks to makes sure a connection between two points is good. There is a complete connection to the load from the battery and back to the battery again. Current is flowing, and by Ohm's Law, voltage drops should only be measured across the load, but no where else.

GOOD TROUBLESHOOTING PRACTICES

- Always make sure you have good electrical connections. Bad connections are arguably the number one source of electrical problems as well as the root cause behind failed components. (If you really don't believe this, I have some pictures of my house with the second floor gutted by fire as proof, thanks to a high-impedance short in an amplifier power cord.)
- Don't try to measure the resistance of something when it is connected. You really have no idea what other paths the resistance measurement might be taking in addition to the one you think you are measuring.
- Never measure the resistance of a live circuit. You will likely blow your meter.
- Check the obvious things first. Connections, especially connections where problems have been known to exist. Think clutch switch. Also mechanical devices and devices exposed to stress (heat, motion, etc). But keep in mind that virtually nothing is impossible. I know I haven't seen it all, but I've seen a lot it, including some really strange and bizarre failures. Almost anything is possible, and the stuff that isn't probably still is.
- Be methodical. Know exactly what you are measuring, and write down the measurements. Don't round off. 12.3 volts and 12.2 volts at two ends of the same wire is significant.

EXAMPLE

- A 60 watt headlight: Should have 12 volts across it and 5 amps flowing through it. 12 x 5 = 60. And the resistance will be 2.4 ohms. 12 = 5 x 2.4
- The resistance measurement of a 60 watt headlight will be essentially zero if measured with a meter. The meter produces insufficient current to heat the element in the headlight and increase its resistance.
- Adding two 55-watt driving lights to the headlight circuit will create a parallel circuit with three paths, one for each light. Each driving light will pull 4.5 amps, for a total of 14 amps between the three lights. This will blow a 10 amp fuse.
- The size of a conductor directly affects how much current it can handle. If the current exceeds what the conductor can handle, the conductor will start to heat up. This can increase the resistance, creating more heat, etc. Best case, something eventually stops working or burns out. Worse case, you have a fire on your hands. This is important as it relates to the conductors

in many motorcycle switches. Pushing 10 amps through a small switch is looking for trouble. That is why relays are used. A relay allows for a small current flow to switch a much large current flow on and off.

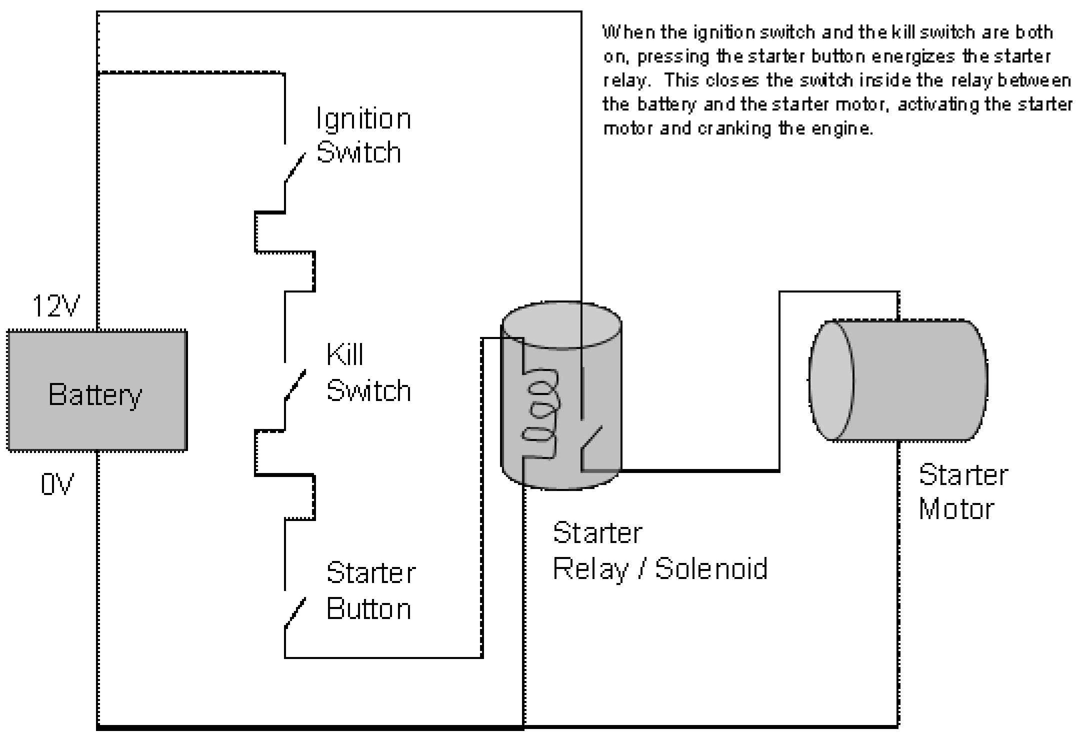
- Using a relay to power a set of driving lights will create the following circuit.
    - Series connection from the battery to the switch.
        - No voltage drop.
        - About 5 amps current flow with switch on.
        - 0 amps current flow with switch off.
    - Series connection from the switch to the headlight bucket.
        - 12 volt drop across the switch with switch off.
        - 0 amps current flow with switch off.
        - No voltage drop with switch on.
        - About 5 amps current flow with switch on.
    - Parallel connection from the headlight bucket, with one path to the headlight and the other path to the relay.
    - Series path through the headlight bulb and back to the battery via the frame.
        - 12 volt drop across headlight with switch on.
        - 5 amps through headlight with switch on.
        - No voltage at headlight with switch off.
    - Series path through the relay and back to the battery via the relay ground wire.
        - 12 volt drop across relay with switch on.
        - Very small current flow (0.1 – 0.2 amps) through relay with switch on.
        - No voltage at relay with switch off.
    - Series path from battery to relay.
        - No voltage drop.
        - About 9 amps current flow with switch on (and relay activated).
        - 0 amps current flow with switch off (and relay not activated).
    - Series connection from the relay to the driving lights.
        - 12 volt drop across the relay with switch off (relay not activated).
        - 0 amps current flow with switch off (relay not activated).
        - No voltage drop across the relay with switch on (relay activated).
        - About 9 amps current flow with switch on (relay activated).
    - Parallel connection from the relay, with one path to each of the two driving lights.
    - Series path through each driving light bulb and back to the battery via the frame.
        - 12 volt drop across each driving light with switch on (relay activated).

- 4.5 amps through each driving light with switch on (relay activated).
- No voltage at driving lights with switch off (relay not activated).
- No current flow.

NOTES

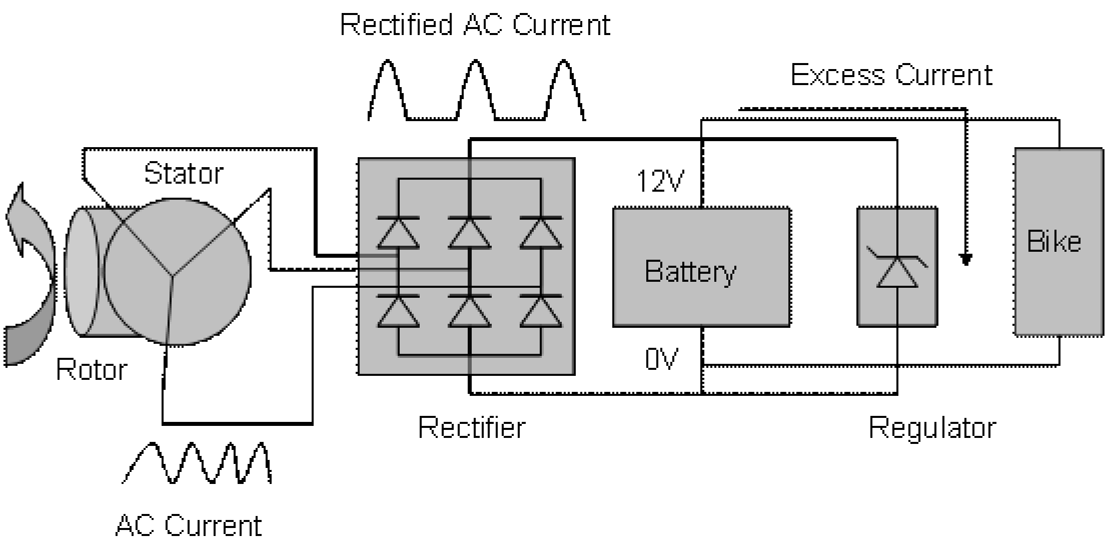
- In general, battery voltage is referred to as 12 volts. When a bike is running, this value will actually be somewhere between 12.5 volts and 14.5 volts.

STARTING SYSTEM



CHARGING SYSTEM

When the engine is running, it turns the rotor. The rotor is made up of permanent magnets. These rotating magnets create a fluctuating magnetic field around the stator windings, which in turn induces an AC electrical current in the windings. The rectifier chops off the negative part of the AC current and feeds the positive part of the current to the battery and to the bike. The regulator siphons off any excess current produced by the stator and sends it directly to ground (battery negative).



With the points closed, current flows from battery positive through the coil primary, through the points and back to battery negative. The only resistance in the circuit should be the resistance of the primary coil.
When the points open, the current flow goes to 0. This change creates a voltage spike in the primary winding, which induces a voltage spike in the secondary winding. The spike in the secondary winding is a much higher voltage, 20,000 – 30,000 volts. This is high enough to jump across the plug gap. The condensors keep the points from pitting by preventing arcing. If you check their resistance, they will start off low and quickly ramp up to infinite.